

TP 14559E

**Development and Trials of a Vessel Self-Positioning System for
the St. Lawrence Seaway Locks**

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by
Yan Lévesque



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Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

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16. Abstract This document deals with the development and trials of a vessel self-positioning system for the Saint Lawrence Seaway locks. A literature search and a study of several companies specializing in measurement and positioning equipment uncovered several promising technologies. Amongst those which would lend themselves best to prototyping, two technologies in particular seem to meet the requirements: the laser range-finder, and image analysis. A laser range-finder device for two dimensional measurement was selected for further testing and rating of performance. A prototype installed at the Côte Sainte-Catherine lock gathered data during the summer and autumn of 2005 in order to verify the range and precision of this type of instrument under various atmospheric conditions. The results show that a single measuring device of this type is capable of positioning full-size vessels. A permanent system installation is recommended in order to improve system performance.				
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16. Résumé Ce document décrit les travaux de développement et d'essais d'un système de positionnement automatisé des navires dans les écluses de la Voie maritime du Saint-Laurent. Une recherche documentaire et à travers différentes compagnies spécialisées dans les appareils de mesure et de positionnement a fait ressortir plusieurs technologies prometteuses. De ces technologies applicables à l'élaboration d'un prototype, deux sont en mesure de respecter les exigences requises : le télémètre laser et l'analyse d'images. La version de mesure en deux dimensions d'un télémètre laser a été retenue afin de vérifier et quantifier ses performances. Un prototype installé à l'écluse de Côte Sainte-Catherine a recueilli des données pendant l'été et l'automne 2005 afin de vérifier la portée et la précision de ce type d'appareil sous diverses conditions atmosphériques. Les résultats démontrent qu'une unité de ce type d'appareil est en mesure de positionner les navires pleine grandeur. L'installation d'un système permanent est recommandée afin d'améliorer les performances du système.				
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EXECUTIVE SUMMARY

The prototype development and research of related technologies discussed here fulfill a Saint Lawrence Seaway Management Corporation need for testing and evaluating technologies capable of assisting a ship's captain or pilot in positioning his/her ship in the Seaway locks. At the present time, it is a member of the personnel at each lock who guides the ship's captain or pilot through to the final position in the lock by using a radio frequency (RF) transmitter.

A literature search and a study of commercially available measurement and positioning equipment have revealed six promising technologies. Amongst those which would lend themselves best to prototyping, two in particular meet the desired requirements: the laser range-finder, and image analysis. An advantage/disadvantage comparison for the relevant technologies has revealed the laser range-finder to be the most efficient means of measuring ship position. A laser range-finder for two dimensional measurement was selected for further testing and rating of performance.

A prototype was installed at the Côte Sainte-Catherine lock during the summer of 2005 and it delivered performance results by the autumn of 2005. This confirmed the detection range and accuracy of this type of instrument under various atmospheric conditions. The factor which most influenced the performance of such a measuring instrument was the reflectivity, or the ability to re-emit light, of a vessel's hull. The instrument's principle of measurement is to calculate the time it takes for light to travel from the device to the obstacle. The light emitted by a laser diode reflects off the obstacle and travels back to the device. The ability of an object to reflect or re-emit light is also known as reflectivity and it varies with the object's colour. The darker the object's colour, the lower its reflectivity. This reduces the instrument's range.

The results show that a single measuring device of this type is capable of positioning full-size vessels. A permanent system installation is recommended in order to improve system performance.

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GLOSSARY

AIS	Automated Identification System
DGPS	Differential Global Positioning System
GPS	Global Positioning System
IMAR	Maritime Innovation
LMS	Laser measurement system (2-D range-finder), also known as laser scanner
RADAR	RAdio Detecting And Ranging
SLSMC	St. Lawrence Seaway Management Corporation

1 INTRODUCTION

1.1 Context

The Saint Lawrence Seaway allows vessels up to 225.5 meters long to transit between the Saint Lawrence River and the Great Lakes. Between Montreal and Lake Erie, the Canadian Lock system includes 13 locks which are 233.5 meters long by 24.4 meters wide.

Traditionally, captains and pilots operate vessels through the locks mainly with the help of visual observations and verbal confirmation of distances given by the lock operators. These information points, combined with their vast experience on how the speed of the vessel should be adjusted to stop the vessel safely at the mooring position, are key elements to the safety of the vessels and lock structure.

Although experience and visual information will remain the main components of a safe passage through the lock, supplementary technologies can improve the safety and efficiency of lock operations by providing mariners and lock personnel with additional tools, enabling them to take safer and better decisions and save time.

1.2 Objectives

The main objective of this project is to develop, deploy and test a system that will integrate sensors and communication technologies adapted to the specifications of the St. Lawrence Seaway locks' configuration and procedures.

The project meets these St. Lawrence Seaway objectives :

- Provide a safe and reliable waterway system : enhanced accuracy in distance measurements and reduced risk of signal confusion will result in safer transits. In addition, the lock operator will become available for safety operations instead of distance estimations, increasing the safety of lock operations;
- Provide a cost-effective system: St. Lawrence Seaway Management Corporation (SLSMC) will benefit from shorter transits and a reduction of its operational costs;
- Provide an environmentally friendly system : A reduction in idling and operating time will result in a reduction of vessel air emissions in the general area around locks, which are often close to densely populated regions.
- Meet customer's transportation needs : Every minute lost adds to the cost of commercial shipping, even more so in light of the current high time-charter rates on the bulk market. Thus, a reduction in transit time will also be a clear economic benefit to shipping companies.

The St. Lawrence Seaway Management Corporation has a strong interest in the development of this system. If the system efficiency and cost effectiveness are proven to be a success, the Corporation will envisage equipping each Canadian lock with a similar system.

The development procedure includes research on technologies which appear capable of efficient positioning. These technologies are compared and evaluated according to SLSMC requirements. A quantitative analysis of each technology reveals the most promising one. From these results, a prototype development is able to confirm the anticipated theoretical performance and areas of improvement.

1.3 Scope of the study

This study seeks to elaborate on a functional prototype installed at a lock, which will permit the lock keeper in charge of ship positioning (also known as the Spotter) to compare the actual position with a position automatically transmitted via an outdoor electronic display and pre-recorded audio messages. In terms of its envisioned performance, it would meet minimum accuracy requirements as established with SLSMC, for favorable atmospheric conditions with good visibility and an absence of inclement weather. Next, factors influencing prototype accuracy such as rain and snow are analyzed, and means of compensating for them are found.

1.4 Layout of a typical lock

The Saint Lawrence Seaway locks have distance marks to position vessels before the change of the water level. The distance divisions in place consist of two stop lines (S for STOP) on each side, followed by division marks in meters which meet at a center line (see Figure 1).

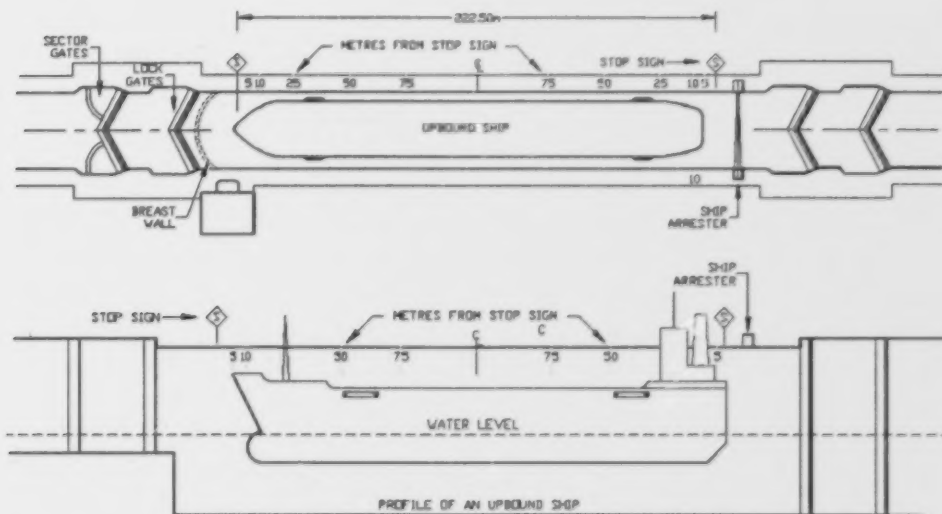


Figure 1 - Dimensions of a lock

The difference between high and low water levels depends on the specific lock. Figure 2 for the Côte Sainte-Catherine Lock shows this lock at its lowest water level, which is approximately 9 meters below the high water level.



Figure 2 – The Côte Sainte-Catherine Lock

1.5 Lock procedures

Vessels move under their own power during their entire transit through the locks. Once a vessel has been securely moored in the lock chamber by a crew of Seaway line handlers, the huge steel lock gates close behind it and valves are put into operation to fill or empty the lock by gravity flow, as demonstrated by Figure 3.

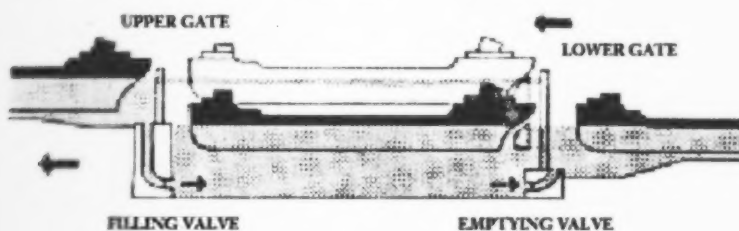


Figure 3 – Lock procedures

The time needed to fill a lock is approximately 11 minutes. As the new level is reached, the forward gates are opened and, at a sign from the spotter, a short blast of the ship's whistle signals "cast off" and the vessel proceeds out of the lock. Some 32 vessels could go through a lock on a very busy day.

Those vessels which arrive at a lower gate, going towards an upper gate, are known as up-bound vessels. Those going through the other way are known as down-bound vessels.

2 SEARCH FOR SOLUTIONS

2.1 Requirements

SLSMC needs will be satisfied by a system which meets the requirements as set out in Table 1, either by developing a customized instrument or by integrating commercially available instruments.

Table 1 – Requirements

1	The position to be transmitted corresponds with the distance between the stop line and the vessel's forward most point above the water line.
2	No vessel modifications required.
3	Functional temperature range of -25°C to +35°C.
4	Instrument must be sheltered from ice.
5	Not influenced by weather conditions such as rain, snow, or fog.
6	Precision controlled by SLSMC.
7	One second position refresh rate.
8	Progressive accuracy of ± 1 meter at the center line, to 0.03 meters at the stop line.
9	No modification to the lock gates.
10	Clear message sent to user.
11	Time-stable measuring.
12	System range from 0 meters (stop line) to 110 meters (center line).
13	Manufactured and assembled to industrial quality standards.
14	Minimal maintenance.
15	Minimized cost.

The safety and health of users, SLSMC personnel and any other individuals are an integral part of all potential self-positioning systems.

2.2 Review of technologies

A literature search and review of commercially available measurement systems uncovered six main technology alternatives, of which the following two were judged to be viable:

1. The laser range-finder
2. Image analysis

The remaining four alternatives were studied and subsequently eliminated as possible self-positioning systems :

3. The Automatic Identification System (AIS)
4. Infrared detectors
5. The echo sounder
6. RADAR

2.2.1 The laser range-finder

A laser range-finder uses a class 1 laser diode. Lasers of this type are inherently harmless, even if inappropriately handled. As a result, they are harmless to the eyes or other parts of the body.

A laser range finder (see Figure 4) emits a very short light pulse (a shot) through a laser diode which is synchronized with a timer. This light pulse will be partially reflected by the first obstacle encountered on its path. The distance between the sensor and the target object is directly proportional to the time required for the light pulse to travel from the instrument to the object and back again.

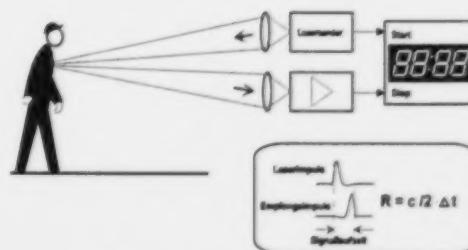


Figure 4 – The laser range-finder

The range-finder solution is feasible for this application if its operating procedure is modified. A Laser Measurement System (LMS) emits a light beam which is deflected by a turning mirror, thereby permitting a 360° sweep on one plane, as shown in Figure 5. The mirror's angular position determines the shot angle, which is used to calculate the object's exact position on one plane in polar coordinates.

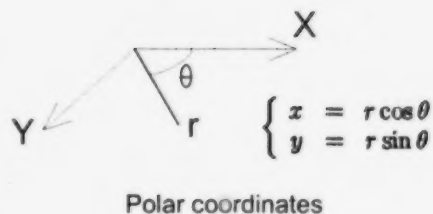
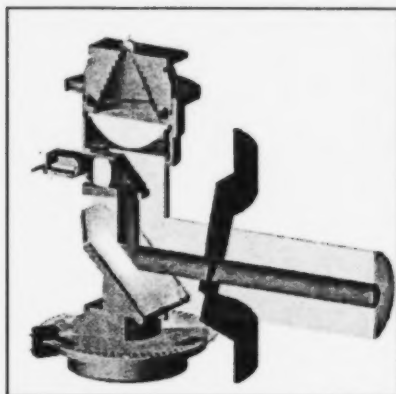
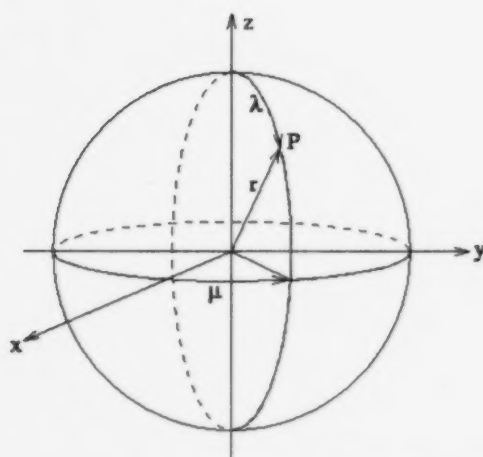


Figure 5 – LMS turning mirror

In order to obtain a three dimensional position, it is necessary to rotate the LMS scanning plane on one of its axes and scan the area top to bottom. The LMS alone calculates the object position through polar coordinates (r, μ) . By combining with another axis of rotation, for instance about the Y axis (angle λ) on Figure 6, it becomes possible to calculate the detected object (P) through spherical coordinates. These coordinates are next converted to Cartesian coordinates X,Y,Z by using mathematical equations.



$$\begin{cases} x = r \sin \lambda \cos \mu \\ y = r \sin \lambda \sin \mu \\ z = r \cos \lambda \end{cases}$$

Figure 6 – Spherical coordinates

The result of this procedure is a set of data points in space, or point cloud, which outlines the bow of a vessel, as shown in Figure 7. This point cloud is used to calculate the distance between the stop line and the vessel's forwardmost part.

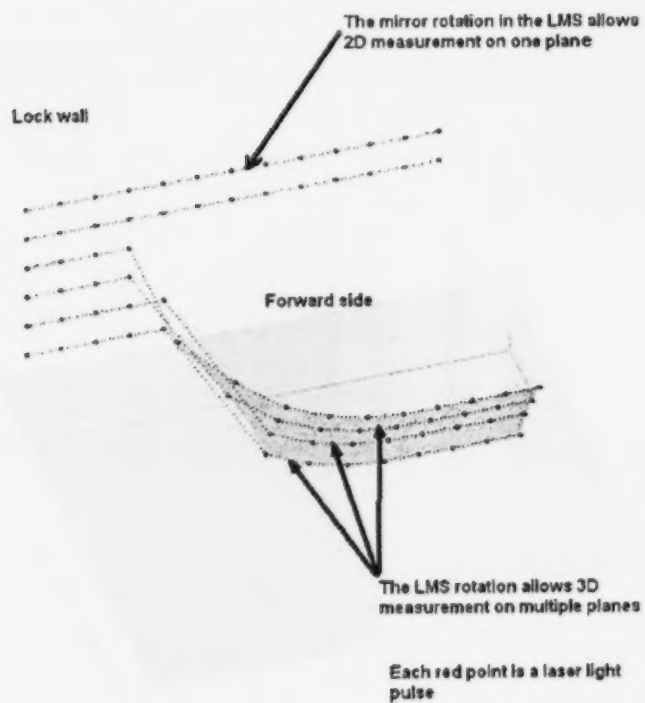


Figure 7- Point cloud

2.2.2 Image analysis

A digital image consists of numerous square pixels of different colours. This pixel set can be mathematically analyzed in order to extract relevant information. The pooling of pixels through software algorithms permits the detection of those pixels which changed colour between two images taken at the same location, as shown in Figure 8. By comparing successive images, the evolution of these changes can be quantified over time.

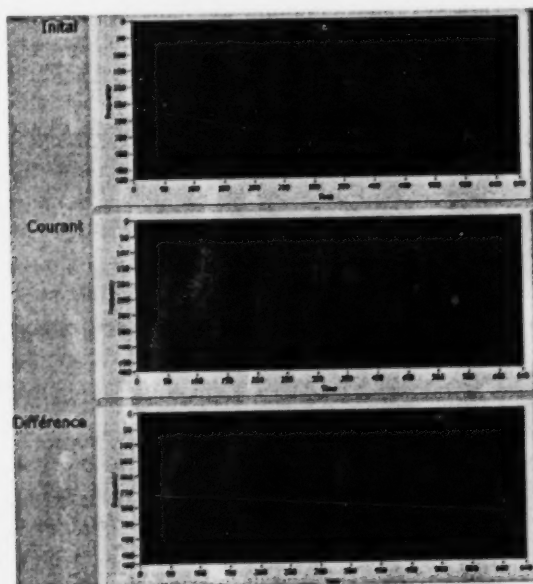


Figure 8 – Image subtraction

Cameras are positioned so as to capture images of the lock perpendicular to its longest dimension. Captured images are next processed by software especially designed for observing and quantifying vessel displacement. The software algorithms analyze each image pixel and so are able to detect the vessel position through colour changes on the screen, following a pre-established threshold. This threshold is set to filter out undesired interference during image processing. Therefore, only large entities such as a vessel will be identified as a target to be processed. Once identified, the software will continue to follow colour changes for each image pixel, which permits it to calculate vessel displacement from each of the images captured by the camera.

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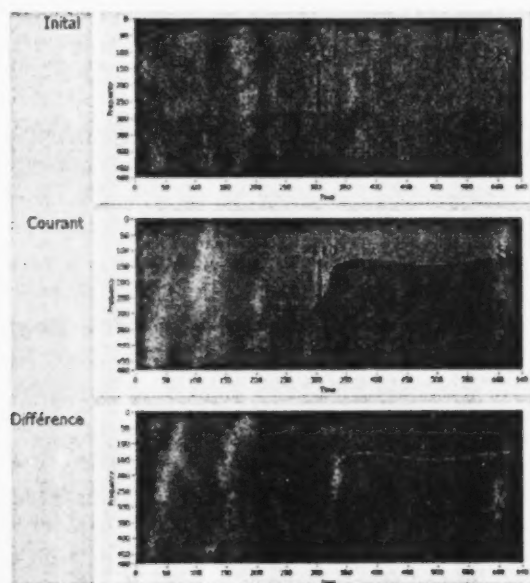


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2.2.3 The Automatic Identification System (AIS)

The Global Positioning System, or GPS, is able to calculate a three dimensional position (latitude, longitude and altitude) instantly and continuously for a user anywhere on Earth. When a GPS receiver is mobile, its speed and direction can also be determined. GPS consists of the following three main components: i) a space element made up of 24 satellites orbiting the Earth, ii) a monitoring element consisting of surveillance stations on the ground and iii) a user element which includes receivers.

The user element consists of receivers used for positioning oneself. These passive receivers only receive signals transmitted by the GPS satellites. Their function is to measure the distance between the receiving antenna and the satellite transmitters. They decode the radio broadcasted messages containing the ephemeris (calculated by ground stations) used in determining the satellite position at the time of observation, and calculate the user position.

The Differential Global Positioning System, or DGPS, uses transmitters located at known geodetic points in order to partially correct for random errors and multi-paths (the pseudo distances) inherent in GPS. For vessel navigation, it is the Automatic Identification System, AIS, which subsequently transmits this information to other receivers.

The delay between two AIS signal receptions is ten seconds when the vessel speed ranges between 0 to 14 knots. During this delay, the exact vessel position is not known. It is also possible to lose the signal for more than ten seconds.

The DGPS antenna position is recorded by the AIS installer. The references for the antenna position are the vessel's sides and points furthest forward and aft. However, the Seaway does not have means at its disposal to verify these dimensions before a vessel arrives at the lock. Therefore, the distances associated with a vessel may be incorrect without anyone being aware.

2.2.4 Infrared detectors

Infrared detection consists of a transmitter sending an infrared beam to a receiver. An obstacle can be detected when it enters between the transmitter and receiver and blocks the reception of the beam.

If this type of instrument is used, it would require the installation of a large number of transmitter-receiver units into the sides of the lock. The resolution will vary directly with the number of units installed. In addition, instruments installed in the lock wall will be vulnerable to collisions with any obstacles or ice.

2.2.5 The echo sounder

The operating principle is as follows: A wave of a set frequency is sent out by the echo sounder. The echo sounder waits for the wave to bounce off an obstacle and return to it. It measures the time passed between the wave's emission and reception: the echo. This way it determines the distance between the sounder, which sent the signal, and obstacle. As well, an analysis of the signal attenuation can help determine the nature of the obstacle.

Several factors of influence make it difficult to analyze echo sounding waves in a lock. Trying to measure horizontally the distance to a hull, which is possibly triangular shaped and inside a straight concrete corridor, will result in the waves bouncing in all directions. Additionally, this type of instrument will have to be installed on the lock gates, leaving them very vulnerable to damaging contact with ice.

2.2.6 RADAR

RADAR sends electromagnetic pulses at radio frequency (RF) through the atmosphere at the speed of light, which is 300,000 km/second. This pulse is reflected by an object in its path and returns to the source like an echo. RADAR determines the distance from the target by measuring the time elapsed between the moment of signal transmission and the return of its echo. The bearing of the detected target is determined by the direction the antenna was pointing while it transmitted the pulse.

There is no RADAR presently available on the market which would permit the detection of a vessel at close range with the required accuracy. The development of a technology for this application could turn into an expensive process with uncertain results.

2.3 Communication method

2.3.1 Outdoor electronic display

The installation of an outdoor electronic display will enable a vessel's captain or pilot to receive, in real time, relevant measurement system information concerning the distance between the forward most point of his/her vessel and a predetermined point of reference such as the stop line. This system will display a kind of universal "mathematical language" easily understood by anyone reading it, no matter what their native language may be.

2.3.2 Audio transmission

Very high frequency (VHF) transmitters could be used to communicate pre-recorded messages at certain pre-established distances to vessel captains and pilots. The vessel would only be notified once the pre-established distance has been reached. It would however be difficult to include very precise information because it is an audio message : The greater the desired precision, the longer the message would be.

2.4 Choosing a technology

To start with, the requirements were reviewed and the two most promising technologies were compared on how well they met these requirements, as shown in Table 2. A check mark (✓) indicates that a particular requirement was met (see Appendix C for the LMS technical data).

Table 2 – Meeting the requirements

	Requirements	LMS	Image analysis
1	The position to be transmitted corresponds to the distance between the stop line and the vessel's forward most point above the water line.	✓	✓
2	No vessel modifications.	✓	✓
3	Operating temperature range of -25°C to +35°C.	✓	✓
4	Instrument must be sheltered from ice.	✓	✓
5	Not influenced by weather conditions such as rain, snow, or fog	Filtering possible, through programming still to be done	Filtering possible, through programming still to be done
6	Precision controlled by SLSCMC.	✓	✓
7	One second position refresh rate.	✓	✓
8	Progressive accuracy of ± 1 meter at 110 meters (center line) to 0.03 meters at 0 meters (stop line).	To be determined. (Limited range. Multiple units required to reach the center line)	To be determined
9	No modification to the lock gates.	✓	✓
10	Clear message sent to user.	Via display and audio transmission	Via display and audio transmission
11	Time-stable measuring.	✓	✓
12	System range from 0 meters (stop line) to 110 meters (center line).	To be determined. (Limited range. Multiple units required to reach the center line)	To be determined
13	Manufactured and assembled to industrial quality standards.	✓	✓
14	Minimal maintenance	✓	✓
15	Minimized cost.	Low cost of adapting the software	More costly: software must be designed

Next, the advantages (A) and disadvantages (D) that both technologies have in common are shown in Table 3 at the beginning, followed by a comparison of differences farther down in the table.

Table 3 – Advantages and disadvantages

LMS (Laser range-finder 3-D version)	Image analysis
Measurement without contact (A)	
Rapid scanning time, permitting measurement of moving objects (A)	
Measure objects in any position (A)	
Does not interfere with access to Seaway during installation (A)	
Acceptable accuracy at the stop line (A)	
Safe for users and personnel, during use of either Class 1 Laser or Image taking (A)	
No reflector necessary (A)	
Locates the forward most point on the ship at all times (A)	
A program is necessary, to filter out objects which do not belong to the vessel and to filter out bad atmospheric conditions such as rain, fog or snow (D)	
Measure through real light contact with an obstacle (A)	Virtual measurement interpreted by a computer (D)
Range is limited by reflectivity, or, how well the laser light is reflected off an object (D)	Range dependent on camera resolution (to be determined)
No lighting required (A)	Lightning required at night (D)
Unaffected by variations in light intensity (A)	Sensitive to variations in light intensity (D)
No influence from background (A)	Background must be filtered by a software (D)

Following a review of this summary of advantages and disadvantages, the LMS emerges as the first choice for the elaboration of a prototype self-positioning system for vessels in the Seaway locks. The chance of success is higher for LMS technology, since software for this type of instrument already exists. Additionally, other locks such as those in the Panama Canal already use this technology in their installations, the only difference being that measurement there is in two dimensions only.

2.5 Trials methodology

1. Starting with an LMS concept, manufacture a prototype system which allows a three dimensional position sweep.
2. Locate this sweeping system alongside a lock so that it can measure the distance between the stop line and vessel in transit.
3. Check that the system's position alongside the lock is the optimal one.
4. Check measuring accuracy.
5. Quantify the ability of the vessel's hull to re-emit light (reflectivity).
6. Verify the disturbing influence of certain factors on LMS measurement such as rain, snow, fog, etc.

3 PROTOTYPE

3.1 Prototype description

The system is divided into five parts :

1. The measuring instrument
2. The outdoor detection system
3. The power supply
4. The control system
5. Methods of communicating the detected distance

3.1.1 The measuring instrument

The system's base element of operation is the LMS. The German based manufacturer SICK® produces an instrument which best responds to the requirements. The LMS 211 (Figure 9) is specifically designed for outdoor use. It has an axis of rotation which permits it to take angle-distance polar coordinates for an object in its field of detection. The scanning angle is 100 degrees, as shown in Figure 10. Its theoretical range varies up to a maximum of 80 meters. Figure 11 and Figure 12 show how the instrument's range is affected by the reflectivity of the detected object. Next, the same graph as that of Figure 12 is shown for fog conditions in Figure 13.



Figure 9 – LMS 211

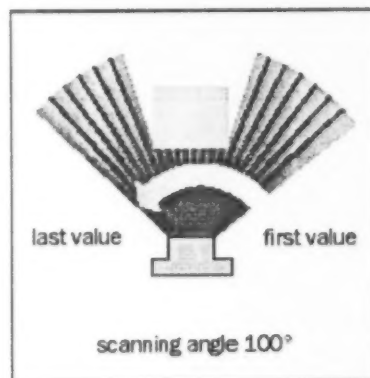
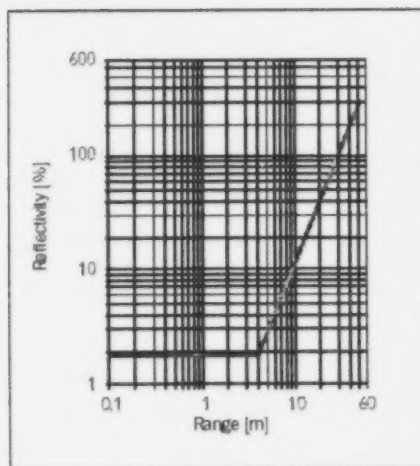


Figure 10 – Scanning angle



Material	Reflectivity
Cardboard, matt black	10%
Cardboard, grey	20%
Wood (raw pine, dirty)	40%
PVC, grey	50%
Paper, matt white	80%
Aluminium, anodised, black	110...150%
Steel, rust-free shiny	120...150%
Steel, very shiny	140...200%
Reflectors	> 2000%

Figure 11 – Reflectivity

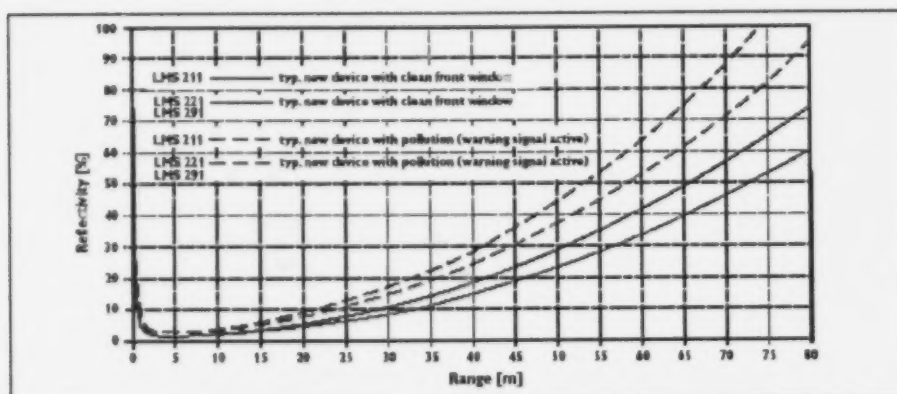


Figure 12 – Relationship between reflectivity and range

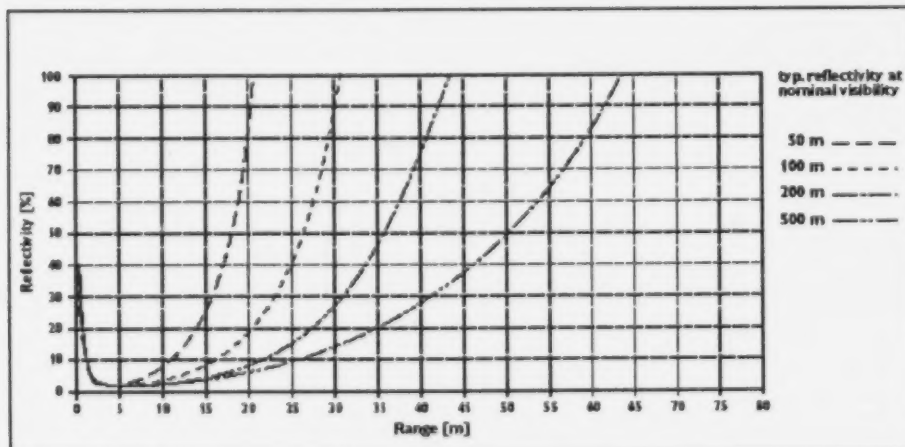


Figure 13 – Range in fog

Measurement accuracy information is presented in Table 4 below :

Table 4 - Measurement accuracy

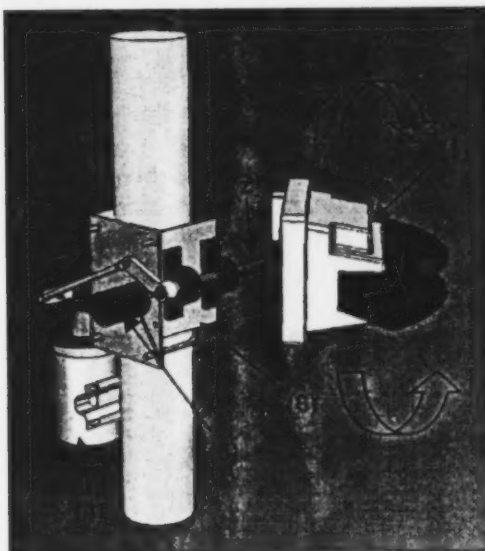
Measurement resolution	10 mm
System error (environmental conditions: good visibility, Ta=23°C, reflectivity 10%...10,000%)	typ. ± 35 mm (mm-mode), range 1...20 m typ. ± 5 cm (cm-mode), range 1...20 m
Statistical error standard deviation (1 sigma)	typ. 10 mm (mm-mode) (at range 1...20 m/ ≥ 10 % reflectivity/ ≤ 5 kLux)

(See Appendix C for more details)

The angular resolution between two consecutive measurements can be selected as 1°, 0.5°, or 0.25°. A 0.5° resolution will correspond to a distance of 0.7 m between two consecutive measurements for an object at the centre of the lock, 75 m away from the LMS unit. At the stop line this distance decreases to 0.13 m.

3.1.2 The outdoor detection system

The following components are necessary for the system to function. Inside an LMS (see Figure 14), a laser diode is mounted on a motor output shaft which turns, thereby permitting it to digitize objects on one plane. A second axis of rotation permits the LMS to tilt up and down, and create a digitalization in three dimensions. The rotating shaft has to be level and aligned with the edge of the lock.



LMS 211 (1)	Allows scanning of an area in one plane.
Rotating shaft (2)	Motor driven, allows the LMS to sweep an area top to bottom.
Gear box (3)	Combined with the motor, provides the desired torque and speed.
Motor (4)	Provides power to the sweeping system.
Position sensor (5)	Transmits the rotating shaft angle to the control system.
Support (6)	Holds components in place.

Figure 14 - Outdoor detection

Measurement accuracy information is presented in Table 4 below :

Table 4 - Measurement accuracy

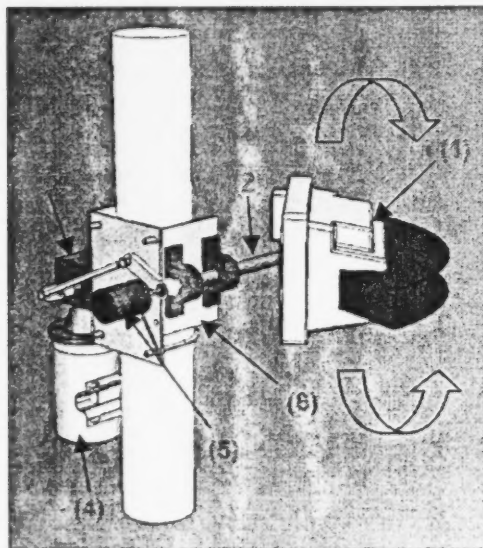
Measurement resolution	10 mm
System error (environmental conditions: good visibility, Ta=23°C, reflectivity 10%...10,000%)	typ. ± 35 mm (mm-mode), range 1...20 m typ. ± 5 cm (cm-mode), range 1...20 m
Statistical error standard deviation (1 sigma)	typ. 10 mm (mm-mode) (at range 1...20 m/ ≥ 10 % reflectivity/ ≤ 5 kLux)

(See Appendix C for more details)

The angular resolution between two consecutive measurements can be selected as 1°, 0.5°, or 0.25°. A 0.5° resolution will correspond to a distance of 0.7 m between two consecutive measurements for an object at the centre of the lock, 75 m away from the LMS unit. At the stop line this distance decreases to 0.13 m.

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Motor (4)	Provides power to the sweeping system.
Position sensor (5)	Transmits the rotating shaft angle to the control system.
Support (6)	Holds components in place.

Figure 14 – Outdoor detection

3.1.3 The power supply

This segment is made up of several elements (see Figure 15), amongst which are a 120 VAC power supply, a 24 VDC voltage source, and a relay. These feed two laser scanner components : the laser diode and internal motor combination which is fed by the relay, and a heating element which is directly fed. The relay is run through a dry contact at the control computer, which feeds it with 120 VAC. A variable speed drive, also computer controlled, determines the motor speed for the outdoor component. A filter is installed between the variable speed drive and 120 VAC supply in order to prevent interference from the drive.

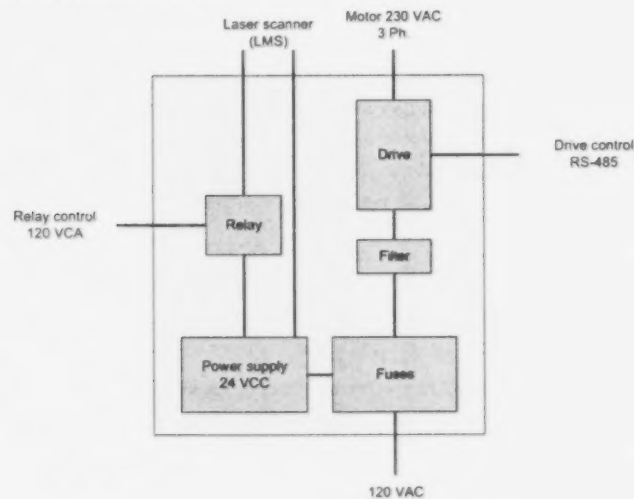


Figure 15 - Power supply diagram

3.1.4 The control system

The entire system is controlled by a computer which has an RS-422/485 communication card (see Figure 16). A custom designed program is able to interpret data from several instruments in order to calculate the distance between the stop line and bow of a vessel.

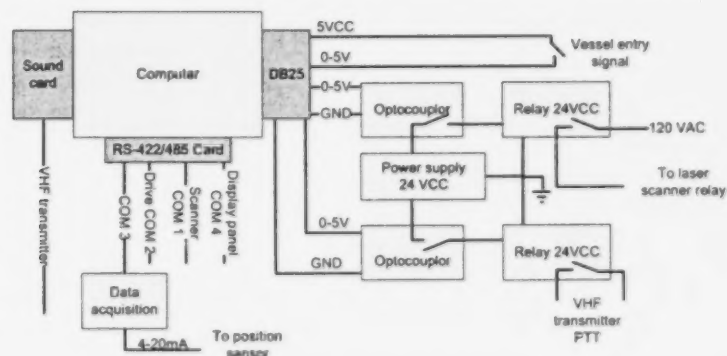


Figure 16 - Control diagram

3.1.5 Methods of communicating the detected distance

Transmission of data is visual and auditory. A three digit outdoor electronic display shows the distance, as calculated by the control computer, in the following way:

- For numbers greater than or equal to 100 : 888
- For numbers from 0.0 to 99.9 : 88.8
- For numbers less than or equal to -0.1 : -8.8
- Stand by : ---

A VHF radio transmitter (see Figure 17) uses one reserved channel to communicate six pre-recorded distances:

- 25 m to go; or "25 mètres à faire"
- 10 m to go; or "10 mètres à faire"
- 5 m to go; or "5 mètres à faire"
- 2 m to go; or "2 mètres à faire"
- 1 m to go; or "1 mètre à faire"
- In position; or "En position"

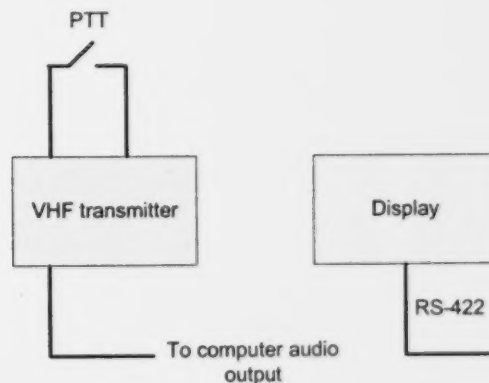


Figure 17 - Communication diagram

3.2 Software description

This section introduces a user interface which is used to program and debug the prototype control software. At the end of its development phase, the positioning system will be capable of functioning without the use of this interface. The interface is made up of an interactive four tab display panel.

3.2.1 Display tab

The "Affichage" (Display) tab permits the user (see Figure 18) to view the lock in three different ways: a plan view, an elevation view and a profile view. These views together give a three dimensional representation of the vessel. The distance between the vessel's bow and the stop line is displayed at bottom center. The section at top right contains three colour indicators that show the state of the outdoor detection system: "En attente" (Stand By), "En marche" (In Motion), or "Alarme" (Alarm). The alarm indicator lights up if there is a problem with the variable speed drive. The section at bottom left contains several items: A push button which simulates the signal given for the arrival of an up-bound vessel; two indicators showing the arrival of an up-bound or down-bound vessel; a switch which activates or de-activates a filter algorithm. This filter permits the disregarding of data points not coming from the ship. The program remains on active stand-by as long as it has not yet received an arrival signal from an up-bound or down-bound vessel. A "STOP" button in the bottom right hand corner stops the program.

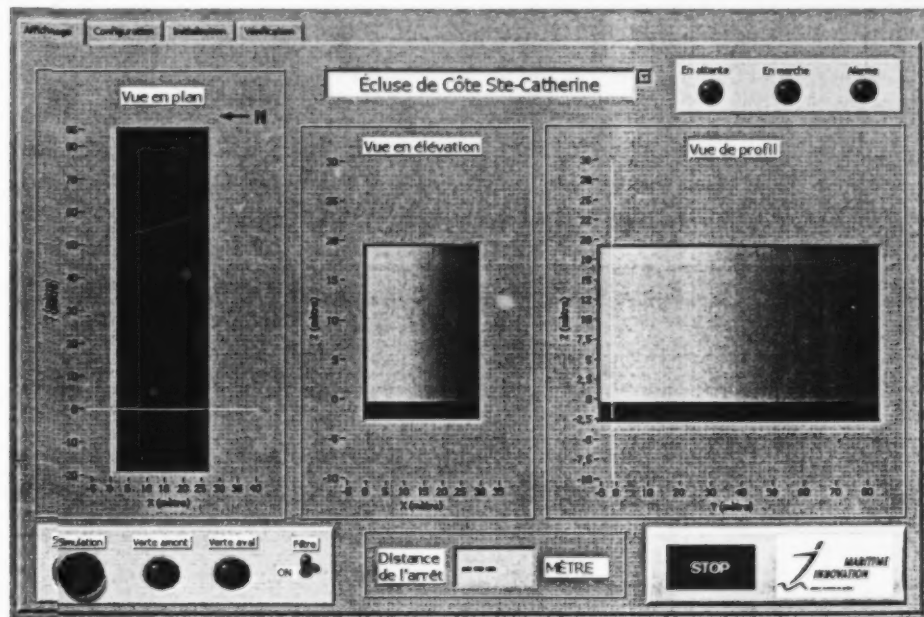


Figure 18 – Display tab

3.2.2 Configuration tab

The configuration tab contains the adjustment parameters for vessel detection (see Table 5 and Figure 19).

Table 5 – Configuration

X min (cm)	Detection corridor parameter. Distance from the scanner to the closest lock wall.
X max (cm)	Detection corridor parameter. Distance from the scanner to the lock wall farthest away.
Y max (cm)	Detection corridor parameter. Scanner range from its position.
Z min (cm)	Detection corridor parameter. Depth of detection in the lock (associated with the base elevation parameter). Needs to be adjusted in terms of leaving space free between the water level and the start of detection.
Élévation de base (Base elevation)	Refers to an arbitrary or actual scanner elevation. It serves as a base for the "Z" parameter.
Nombre de scan. Affiché (Scan displayed)	Sets the number of points displayed in the "Affichage" tab's three (3) "Vue" windows.
Scan. Pour dist. Min. (Scan for min. dist.)	Refers to the number of elements included in the vector, serving to identify the minimum distance to display.
Décalage arrêt (m) (Stop off-set)	Serves to align the program zero reference with the lock's stop line. Depends on scanner location.
Enregistrement (Record)	Allows storage of vessel transit data.
Fichier (File)	Directory which contains the vessel transit data.
Panneau (Display)	Turn on or turn off the outdoor display.
Limite du panneau (Display limit)	The distance limit where the showing of distance on the outdoor electronic display begins, as shown in m.
Voix (Voice)	Distance transmission (or no transmission), audible via radio transmitter.

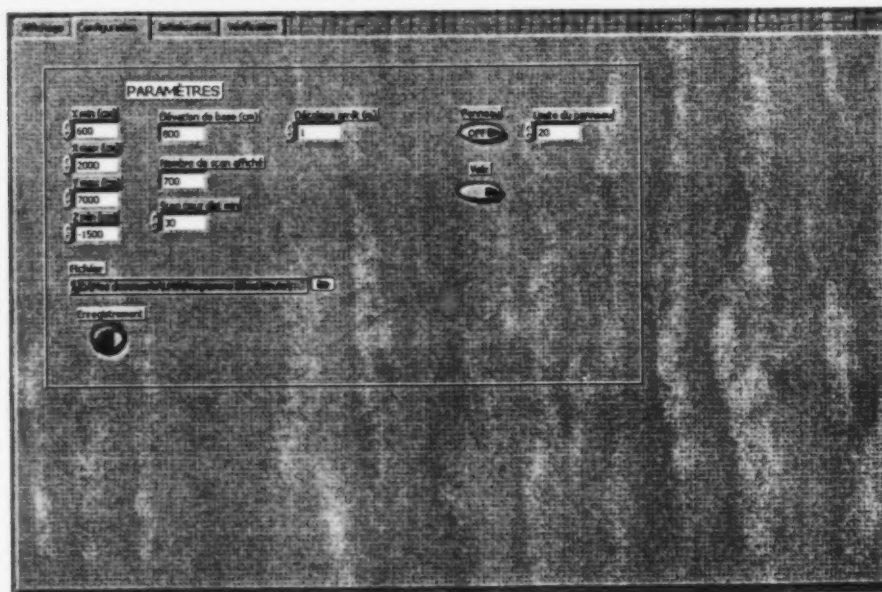


Figure 19 – Configuration tab

3.2.3 Initialization tab

The "Initialisation" (Initialization) tab is required only when the LMS 211 is used for the first time (see Figure 20). Once connected to power, it is possible to automatically configure the LMS by clicking on the "OK" button and waiting until the end of the procedure, indicated by the progress bar.

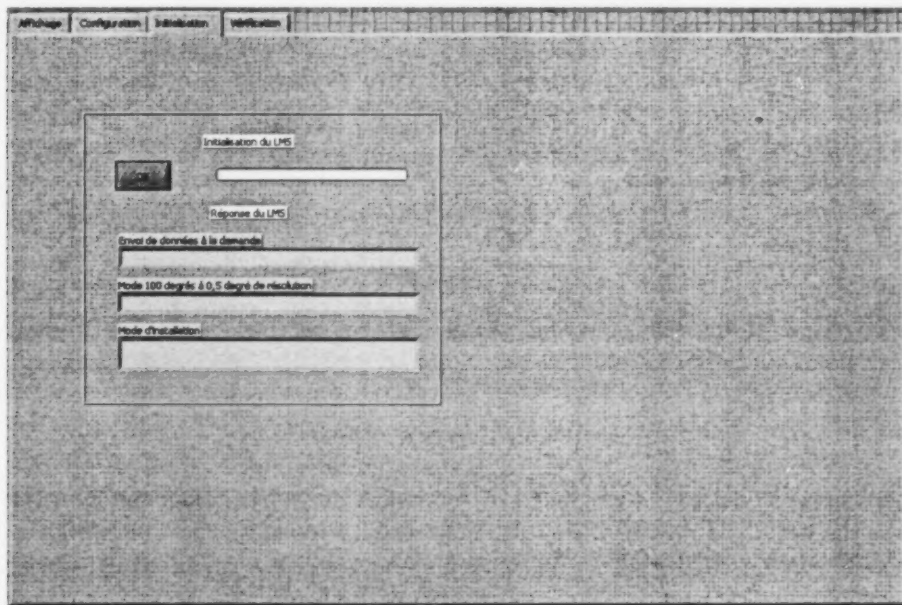


Figure 20 – Initialization tab

The last tab, "vérification", is locked and is not required by the user.

4 TRIALS

4.1 Trial description

4.1.1 Objective

To verify the feasibility of using the LMS 211 instrument (manufactured by SICK®) for the automatic display of vessel position as referenced from the stop line. The factors of influence are the rate of reflectivity of the laser beam on the vessels' hulls, the instrument's position and the outdoor visibility conditions.

4.1.2 Trials chronology

A prototype for an automated vessel positioning system based on an LMS 211 was installed in June 2005 at the Côte Sainte-Catherine Lock.

The object of this installation was to obtain the distance between the forward most point of the vessel and the lock's stop line. The trials attempt to expose variables which influence the instrument's accuracy and range.

The first set of data was obtained on July 17th 2005, which enabled the start of the optimization of software programming. During August and September of 2005, system functionality was validated. The first reliable and verifiable data were recorded in October 2005.

4.1.3 Data processing

The LMS processes information by gathering all captured points and subsequently sorting and filtering them. The first stage consists of identifying a detection corridor in the lock channel which corresponds to the maximum vessel dimensions. Under these conditions, everything which is outside of this detection corridor will not be taken into account. The result obtained is presented in the form of a reference point cloud in Cartesian coordinates XYZ, which represents the vessel's bow. Of all these points, only those whose coordinates are closest to zero, or the stop line, are kept. These coordinates represent the distance to be communicated to the captain or pilot. Filtering becomes necessary when something which does not belong to the vessel, such as a bird or snow flakes for example, is perceived in the bow detection corridor.

4.2 Results and analysis

4.2.1 Instrument position

For the trials, the LMS was located on an approximately three meter high mast which was upstream, on the North-West side of the Côte Sainte-Catherine Lock (Figure 21). This position permits the instrument to sweep the entire lock for up-bound vessels at lowest water levels. Upward sweeping of the LMS has to be avoided in order to protect the front glass "objective" from bad weather. Water drops or snow accumulation could affect the data.

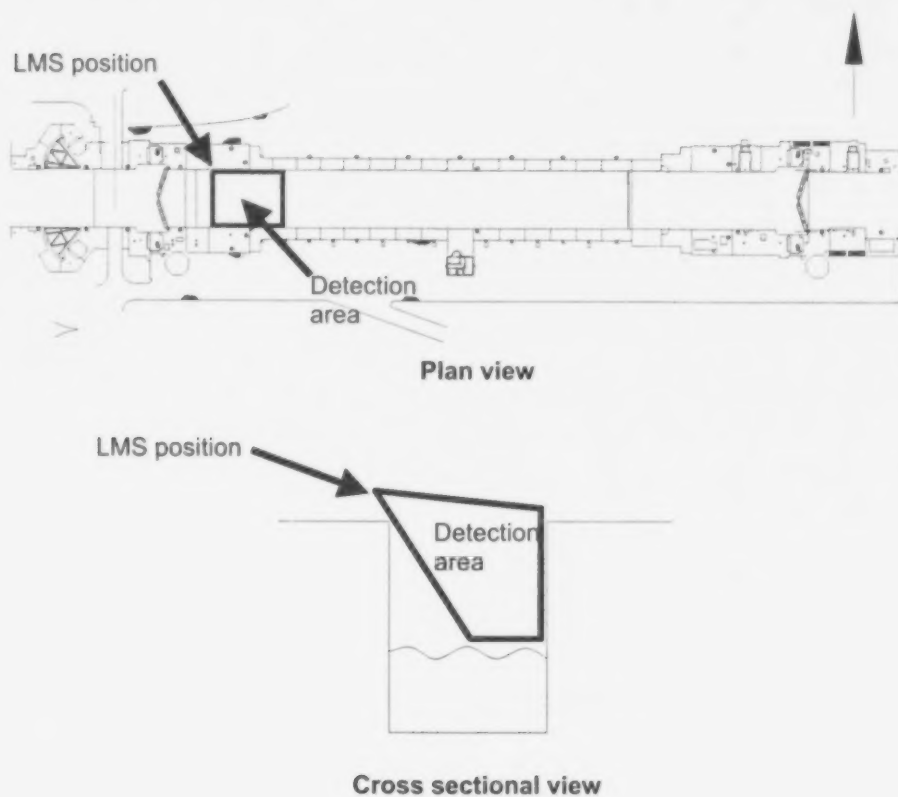
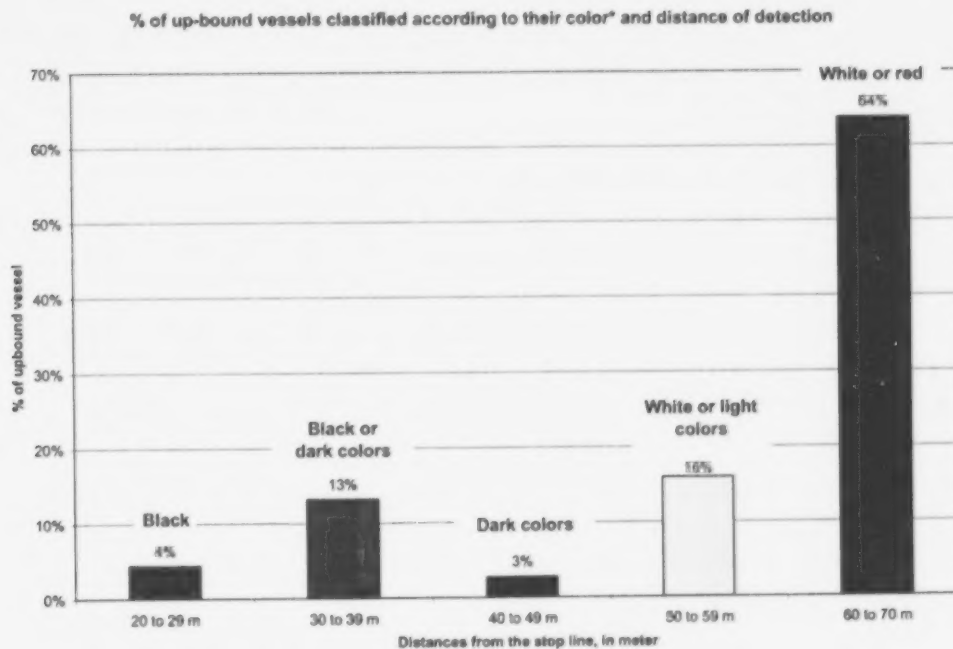


Figure 21 - LMS position

4.2.2 Instrument range

The instrument range is decided by two variables: The reflectivity of the vessel's hull, and the meteorological conditions. The maximum range is 70 m. The following graph in Figure 22 shows the percentages of up-bound vessels at the distance from the stop line where they were detectable by the positioning system. Each distance detection range corresponds to a vessel hull colour. It is therefore evident from this graph that 64 % of vessels were detected between 60 and 70 m from the stop line and that these vessels' hulls were mainly red or white. The sum of the five columns in the graph corresponds to 100% of up-bound vessels sampled.



*The most reflective colour on the forward section of the hull

Figure 22 – Percentages of vessels at detectable distances

4.2.2.1 Hull reflectivity

The trials enabled a strategy for obtaining the desired instrument range. Table 6 and the graph in Figure 22 compare three methods of deciding on the minimum distance requirements which would make the positioning system's distance transmissions reliable for vessel captains/pilots. The first table, "By transit" shows the percentages of all vessels which transited through the lock, at the distances where they were detected. This includes vessels which transited through more than once. This table can be interpreted as follows: The first column, "% of vessels", shows for example that 18 % of vessels in the sample were detected at 60 m from the stop line. The second column,

"cumulative %", shows that 64 % of vessels in the sample can be positioned from within this 60 m distance from the stop line. The second table, "Vessels moored at zero to 15 m", excludes all vessels moored at more than 15 m from the stop line. The third table, "By vessel type", re-examines all vessels listed in the "By transit" table, but for one transit only. If a vessel had transited more than once, only a single transit was taken into account. These three tables have been summarized on a graph in Figure 23 where the cumulative % at a given distance is represented by a column.

Table 6 – Summary of results

By transit			Vessels moored at 0 to 15 m		
Distance (m)	% of vessels	Cumulative %	Distance (m)	% of vessels	Cumulative %
20	4%	100%	20	7%	100%
30	13%	96%	30	15%	93%
40	3%	82%	40	0%	78%
50	16%	80%	50	7%	78%
60	18%	64%	60	11%	71%
70	46%	46%	70	60%	60%
Total	100%		Total	100%	

By vessel type		
Distance (m)	% of vessels	Cumulative %
20	6%	100%
30	14%	94%
40	3%	80%
50	17%	77%
60	21%	59%
70	39%	39%
Total	100%	

Data used :

Sampling of up-bound vessels in transit:

By transit = 182 transits

Vessels moored at zero to 15 m = 109 transits

By vessel type = 116 transits

By way of reference, 2600 transits in both directions occurred in 2004.

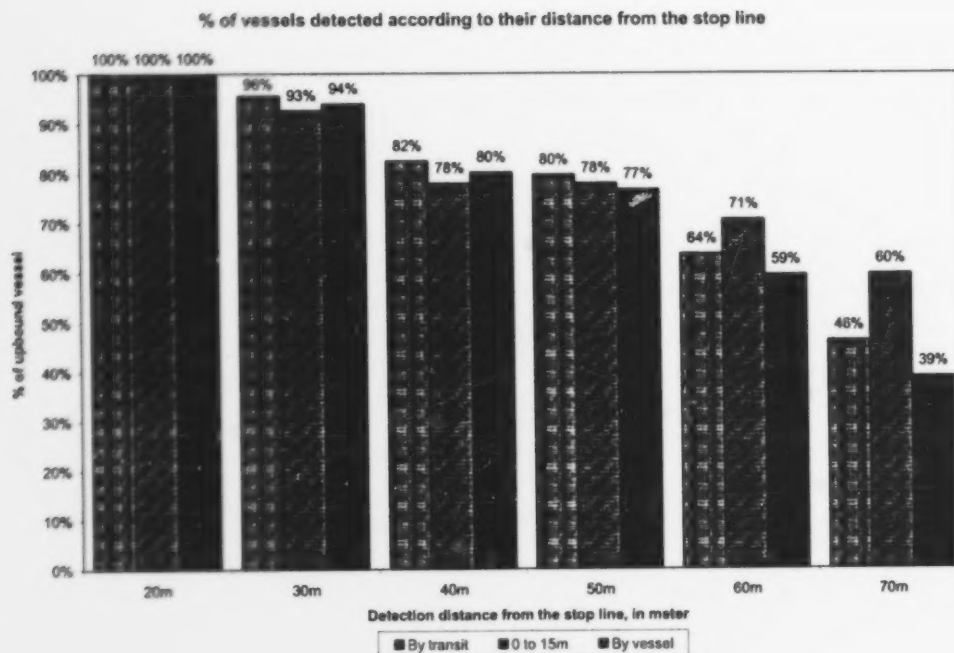


Figure 23 – Detection distances

4.2.2.2 Meteorological conditions

Snow flakes are dense enough to reflect light emitted by the LMS laser diode. This reflection causes coordinates to be transmitted for fictitious points that do not belong to the vessel.

Rainfall only slightly affects the measurement quality and accuracy. An analysis for each vessel's passage did not reveal a noteworthy difference for the LMS range.

5 CONCLUSIONS

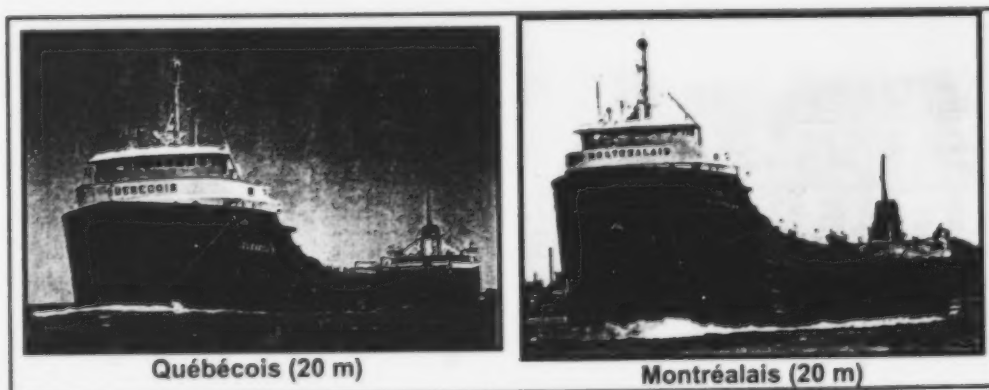
1. Range of 20 m for present conditions.

The relatively low reflectivity of black or dark blue hulls causes them to be completely detectable at only 20 m from the stop line, as measured from the forward most point on the vessel. Three possible solutions could produce a greater detection range: the installation of instruments at 20 m intervals; painting a white or red line on the bows of darker coloured vessels to increase their reflectivity, as shown on Figure 24; or installing a large reflective target on the forward most part of the vessel.



Figure 24 – Vessel with white line

The following are examples of vessels that have colours which inhibit good laser diode light reflection. Their detection distances are also listed : Redhead (30 m); Seneca (30 m); Ziema Cieszynska (30 m); Ziema Tarnowska (30 m); Milo (35 m); Lake Maya (35 m); Menominee (35 m); Toro (35 m); Antikeri (30 m). Figure 25 shows other vessels detectable at 20 to 35 m.

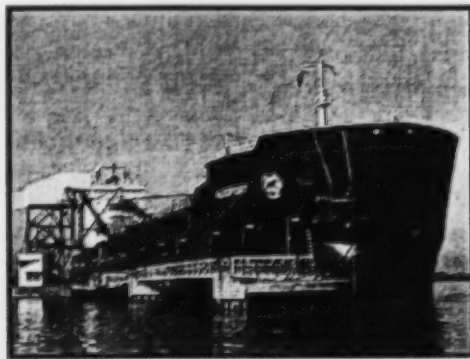


Québécois (20 m)

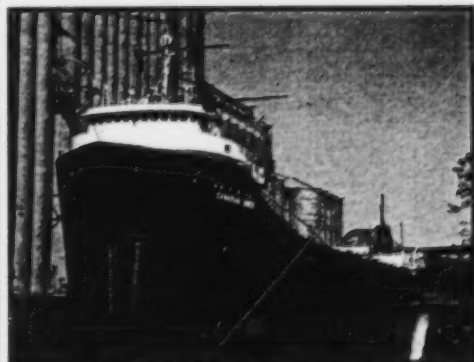
Montréalais (20 m)



Algosoo (30 m)



Algoport (35 m)



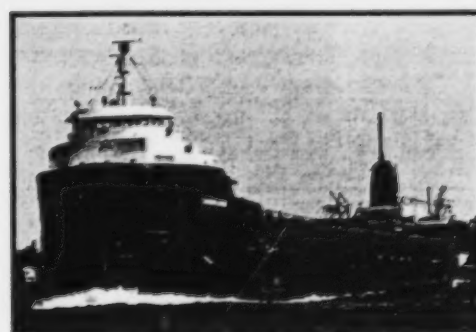
Canadian Miner (20 m)



Canadian Ranger (25 m)



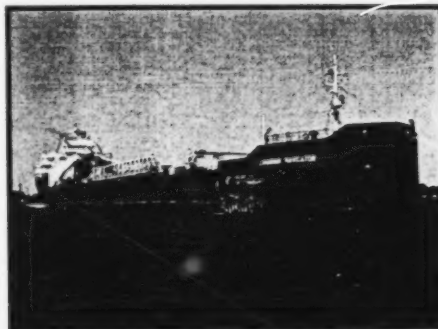
Canadian Progress (20 m)



Canadian Leader (20 m)



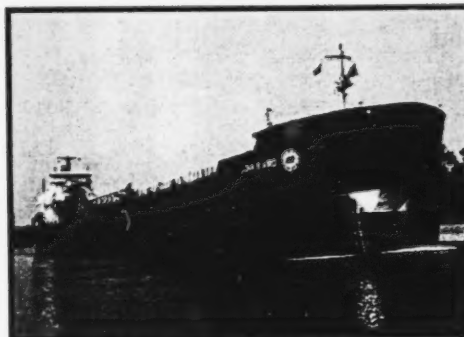
Canadian Enterprise (25 m)



Canadian Navigator (30 m)



Gordon C. Leitch (30 m)



John B. Aird (35 m)



Saunière (25 m)

Figure 25 – Examples of vessels detectable at 20 to 35 m

2. Outdoor display and audio transmission as functional means of communication.

The prototype is capable of conveying, via an outdoor display, the distance separating the vessel bow from the stop line. It can likewise be concluded that recorded messages, corresponding to the six pre-established distances, can be transmitted via VHF transmitter.

6 RECOMMENDATIONS

Certain aspects have to be taken into consideration in the implementation of such a system to help improve performance.

1. A higher detection system position for down-bound vessels.

A similar system installation on the downstream side for down-bound vessels will foreseeably require a tower high enough to deal with the highest vessels expected. This is to avoid having to sweep upwards and expose the LMS front glass pane to bad weather.

2. The installation of a second LMS on each side.

Snowfall interferes with the laser light by causing it to reflect off the flakes, leading to fictitious data points during detection. A filtering program should be capable of isolating these points and keeping only those belonging to the vessel. This type of program will have an efficiency limit which can not yet be determined for the time being. Trials during periods of snow will first be necessary. There is another potential concept which may help to further reduce snow induced fictitious data points and thereby improve system reliability. A second LMS could be installed in the same location. However, it would sweep in the opposite direction from the first LMS. A sweeping subtraction from each LMS would eliminate points which were not captured by both LMS units. The efficiency of this concept rests on the probability that the chance of detecting a particular snowflake by both LMS units at the same location is very small. In addition, a second unit would increase resolution because twice as many points will be collected at a given moment in time. This will give a greater margin of safety in case one unit malfunctions.

3. Necessity of adding more outdoor detection systems in order to meet all requirements

Requirement number 8 (see Table 1), "*Progressive accuracy of ± 1 m at the centre line, to 0.03 m at the stop line*", as well as requirement number 12, "*System range from 0 m (stop line) to 110 m (centre line)*", cannot be met if a single LMS is installed at the stop line at each end of the lock for up-bound and down-bound vessels. This is because the detection distance is limited to 20 m for vessels with dark hulls. If the required 110 m range is divided by the 20 m LMS limitation, it can be concluded that 6 LMS units would be required for each end, or a total of 12 LMS units per lock.

4. Checking for laser diode wear effects.

It will be necessary to run the LMS non-stop for an extended period of time, in order to check out the effects of laser diode wear on the instrument's range and accuracy.

BIBLIOGRAPHY

1. Innovation maritime, *Description des concepts*, November 25, 2004, 17 p.
2. Innovation maritime, *Traitement de l'image*, December 7, 2004, 11 p.
3. Innovation maritime, *Étude des options*, January 31, 2005, 25 p.
4. Innovation maritime, *Prototype scanneur laser*, June 9, 2005, 25 p.
5. Innovation maritime, *Essais du scanneur laser*, January 13, 2006, 14 p.
6. Innovation maritime, *Manuel de l'utilisateur*, January 13, 2006, 13 p.
7. SICK Optic Electronic, *Laser Measurement System: Technical Description*, June 2003, 40 p.
8. SICK Optic Electronic, *LMS Telegram Listing*, April 4, 2003, 128 p.
9. Saint-Lawrence Seaway Management Corporation, *The Seaway handbook*, 2002 Edition, 117 p.

APPENDIX A – Photographs of the Côte Sainte-Catherine Lock

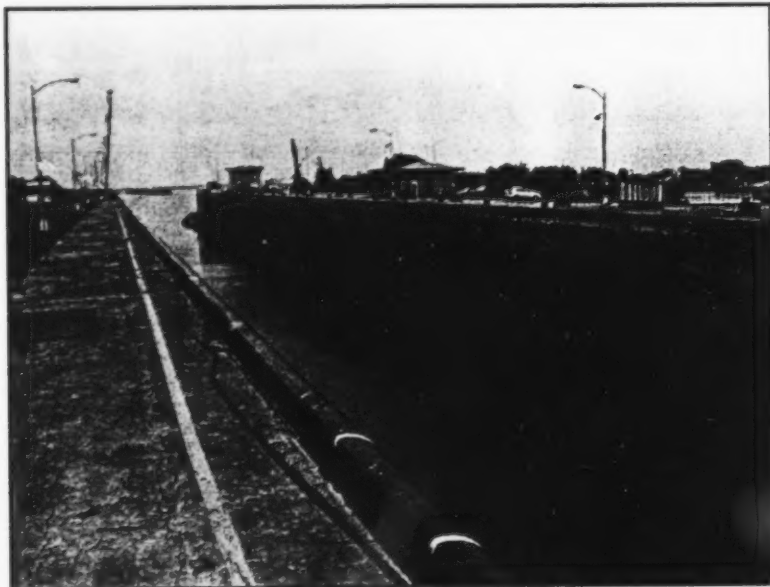


Figure A-1 – Facing East from LMS position

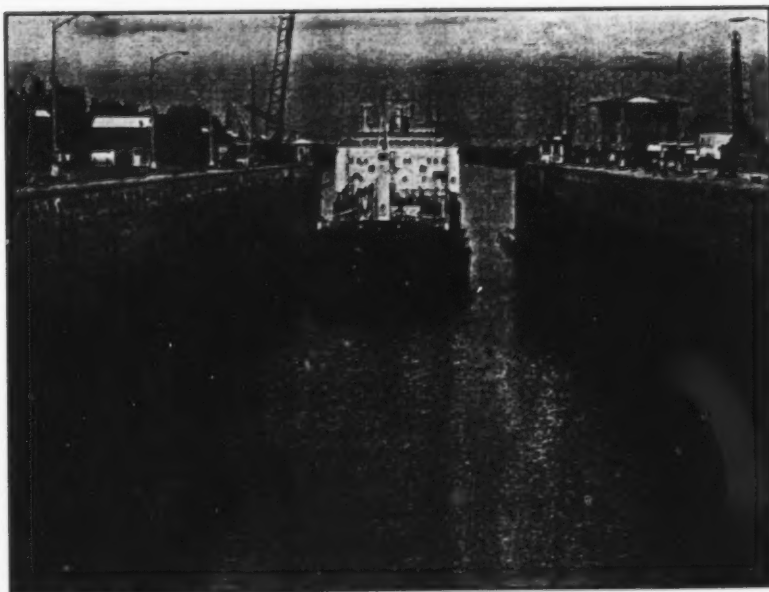


Figure A-2 – During vessel entry, facing East

APPENDIX B – Photographs of the prototype

The prototype is located at the North-West section of the Côte Sainte-Catherine lock.

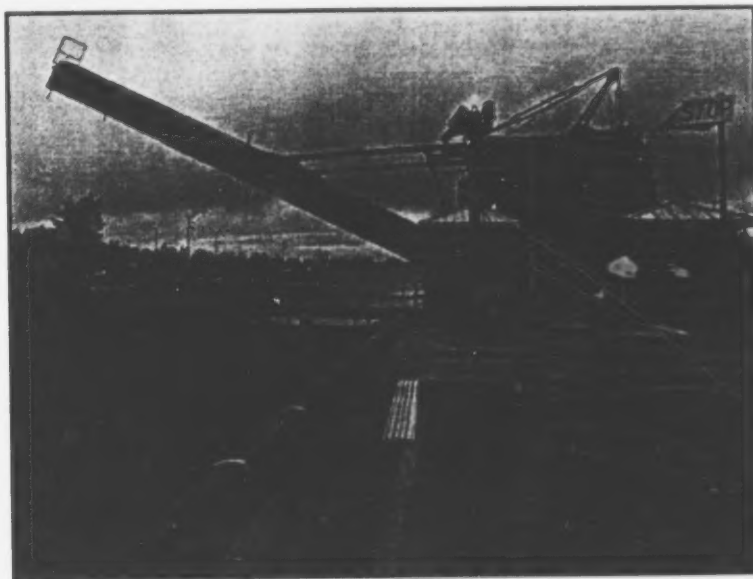


Figure B-1 – Facing West



Figure B-2 – Facing East



Figure B-3 – Facing North

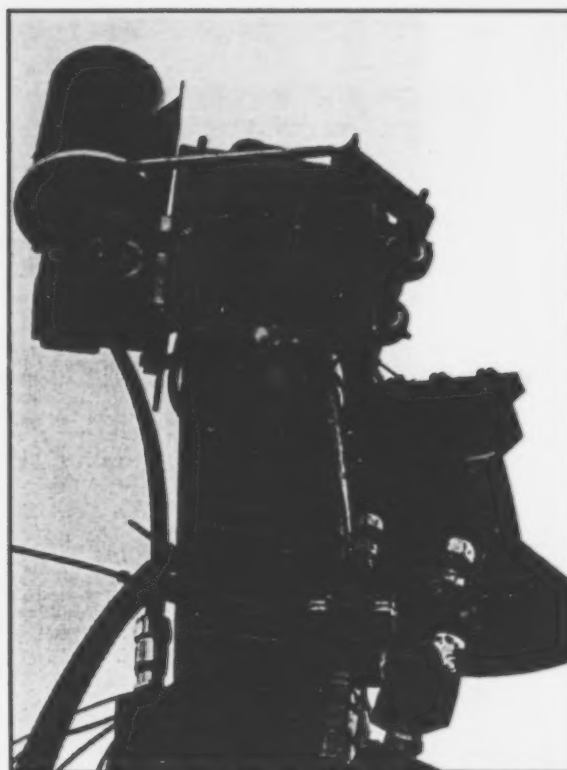


Figure B-4 – Detail, facing East



Figure B-5 – Detail, facing South

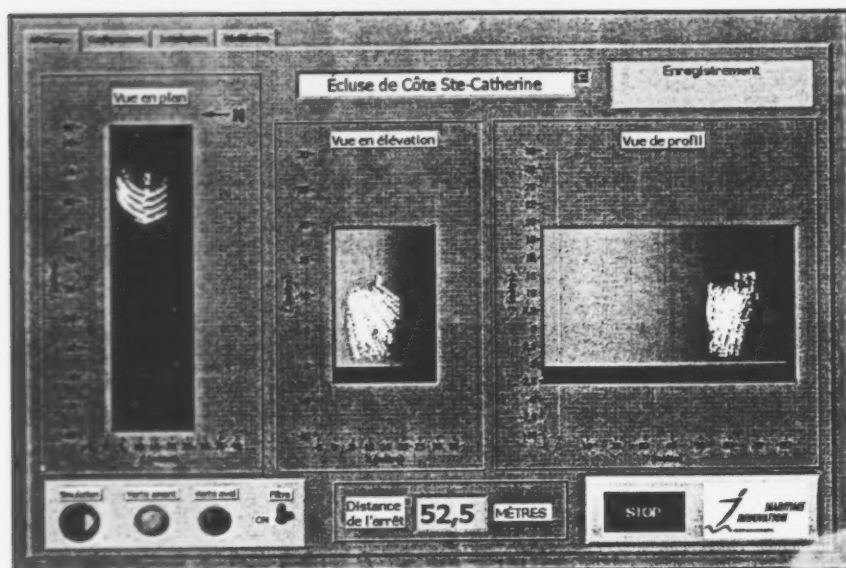
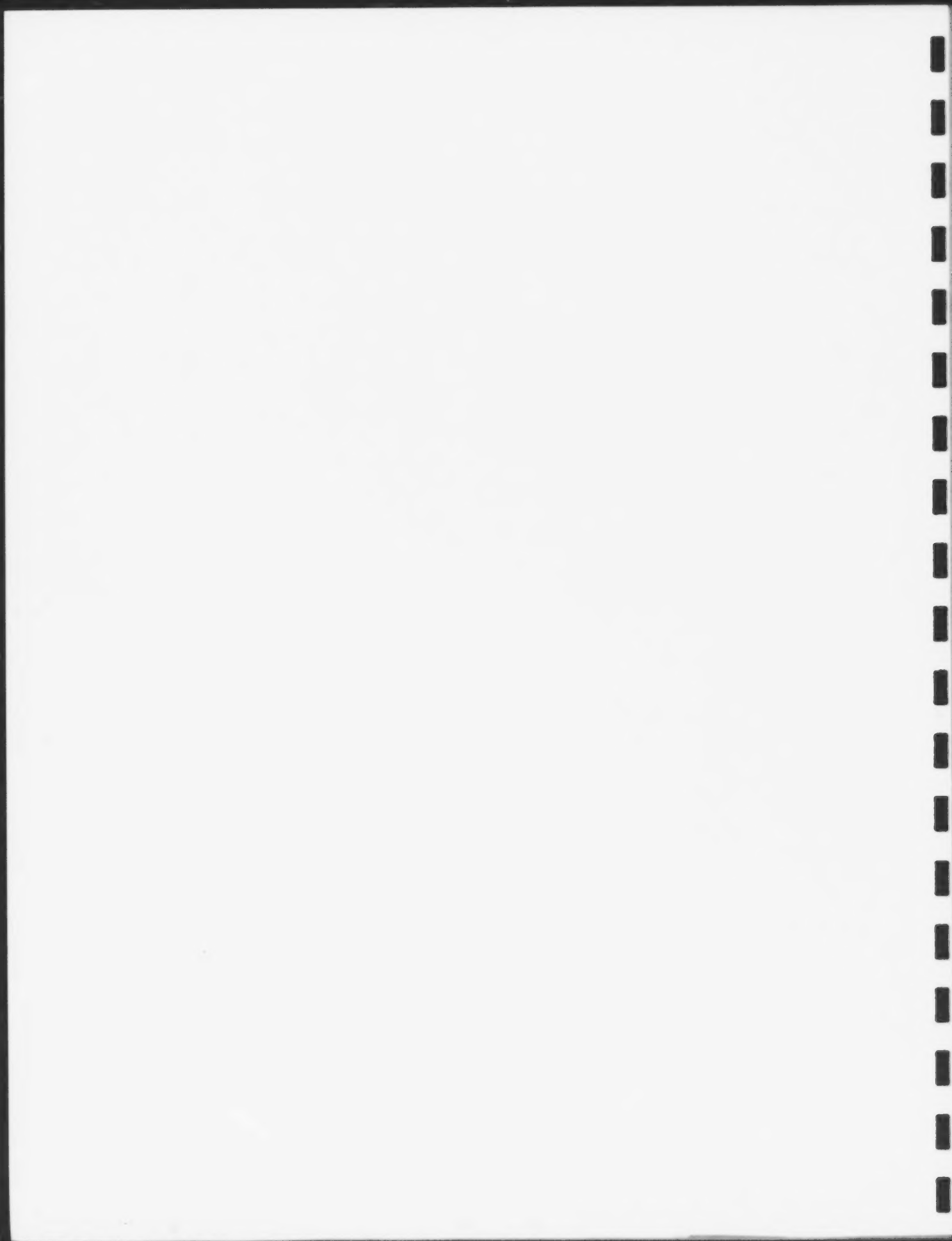


Figure B-6 – Sample view of screen during vessel arrival



APPENDIX C – LMS 211-30206 Technical Data

Measurement accuracy definitions:

Resolution

The resolution of a measuring device is the smallest possible distance other than zero between two consecutive individual measurement values. The resolution can be reduced by using averaged values.

Systematic error

Systematic error is the sum of all the deviations over a defined extent of range and reflectivity, which cannot be reduced even using averaged values.

Standard deviation

The standard deviation is calculated using at least 100 measurement values of a target with a certain reflectivity at a certain distance with a certain amount of illumination.

¹⁾ Angular resolution 0.25° not possible in the monitoring fields mode.

General

Range	max. 80 m
Angular resolution	0.25° ¹⁾ /0.5°/1° (selectable)
Response time	53 ms/26 ms/13 ms
Measurement resolution	10 mm
System error (environmental conditions: good visibility, T _a =23°C, reflectivity 10%...10,000%)	typ. ± 35 mm (mm-mode), range 1...20 m typ. ± 5 cm (cm-mode), range 1...20 m
Statistical error standard deviation (1 sigma)	typ. 10 mm (mm-mode) (at range 1...20 m/ ≥ 10 % reflectivity/ ≤ 5 kLux)

Electrical

Data interface	RS 232/RS 422 (configurable)
Transfer rate	9.6/19.2/38.4/500 kbaud
Switching outputs, standard variants	3xPNP; typ. 24 V DC OUT A, OUT B max. 250 mA, OUT C max. 100 mA OUT A, OUT B (relay) max. switching voltage 48 V DC/26 VAC (protected low voltage, safe isolation from mains) max. switching current 0,7 A; max. switching power 30 W; OUT C/weak (PNP) typ. 24 V DC, max. 100 mA
Switching outputs, relay variants	
Supply voltage (scanner-electronics)	24 V DC ± 15% (max. 500 mV ripple) current requirement max. 1,8 A (incl. output load)
Supply voltage (heating)	24 V DC (max. 6 V ripple) current requirement max. 6 A (cyclic) approx. 20 W (without output load) plus heating with approx. 140 W
Power consumption	
Electrical protection class	safety insulated, protection class 2
Laser protection class	1 (eye-safe)
Interference resistance	acc. to IEC 801, part 2-4; EN 50081-1/50082-2
Operating ambient temperature	-30...+50 °C (warming-up time approx. 120 min. at T _{min})
Storage temperature	-30...+70 °C

Mechanical

Enclosure rating	IP 65 and IP 67
Weight approx.	approx. 9 kg
Dimensions approx.	350x265x200 mm
Vibration fatigue limit	acc. to IEC 68 part 2-6, table 2c, frequency range 10...150 Hz, amplitude 0.35 mm or 5 g single impact IEC 68 part 2-27, table 2, 15 g/11 ms permanent vibration IEC 68 part 2-29, 10 g/16 ms. Shock absorbers are recommended for heavy vibration and impact demands (e.g. AGV applications).

